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A TENTATIVE DETECTION OF PROPANE ON JUPITER AND SATURN

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ABSTRACT

High-resolution 10 μm spectra of Jupiter and Saturn obtained with a cryogenic Fabry-Perot spectrometer are presented. They provide the first evidence for propane (C_3H_8) on Jupiter. An emission feature blended with the R7 line of acetylene (C_2H_2) at 748 cm^{-1} is tentatively identified with the ν_{21} fundamental of propane. A similar feature is observed on Saturn, where propane has tentatively been detected by the Voyager spacecraft (Hanel et al., Science 212, 192). The intensity of this feature on both Jupiter and Saturn is presented.

I. INTRODUCTION

The study of hydrocarbon photochemistry in the atmospheres of the outer planets has been a subject of much investigation since the discovery of ethane and acetylene emission on Jupiter by Ridgway (1974). Recent reviews of the subject include those by Strobel (1983) and Atreya and Donahue (1979). The infrared spectrometers on both Voyager spacecrafts also provided new data on the stratospheric emission bands of Jupiter, Saturn, and Titan (Hanel et al., 1979; Hanel et al., 1981). The results for Titan were especially spectacular since emission bands of hydrogen cyanide, cyanogen, cyanoacetylene, methylacetylene, propane, and diacetylene were observed for the first time.

We report here the probable detection of propane (C_3H_8) on both Jupiter and Saturn. This gas was previously detected on Titan (Maguire et al., 1981) and a tentative detection on Saturn was also reported (Hanel et al., 1981).

Spectra of Jupiter and Saturn were obtained with a cryogenic 10-μm Fabry-Perot spectrometer which had been used previously to detect HCN on Jupiter (Tokunaga et al., 1981) (a description of this instrument is given by Beck et al. [1982]). The observations, prompted by the announcement of the detection of propane on Titan by the Voyager 1 IRIS team (Hanel et al. 1981), were made with the NASA Infrared Telescope Facility at Mauna Kea.

A 6-arcsec aperture centered on the planets was used. The spectral resolution was 0.09 cm^{-1}. Since the free spectral range of the Fabry-Perot spectrometer was very small, the central frequency was carefully determined by comparison to NH_3 spectra obtained by the spectrometer through a gas cell mounted at the telescope. The position of the ν_{21} fundamental of propane at 748 cm^{-1} was observed and the spectra of Jupiter and Saturn are shown in Figs. 1 and 2. Observations of Titan were also obtained, but they were not of sufficient quality to be published.

We show spectra of the R15 line of C_2H_2 in Figs. 3 and 4 to demonstrate that the instrumental line profile of the Fabry-Perot spectrometer is symmetric and that the R7 line is a blend of emission features. Spectra of the R3 and R5 line of C_2H_2 on Jupiter and Saturn are also symmetric, but the R21 line is blended with C_2H_6 emission lines.

We identify the blend with the R7 line of C_2H_2 as emission from the ν_{21} fundamental of propane for the following reasons. First, observations by Hanel et al. (1981) show evidence for propane on Saturn, and our spectrum of Saturn is consistent with those results. Second, the blended feature is consistent with the position of the ν_{21} fundamental line position to within the accuracy of existing laboratory data (D. Jennings and L. Giver, private communication). Older data by Gayles and King (1965) give a position of 748.10 cm^{-1} in vacuum, in accord with Figs. 1 and 2. Third, the blended feature does not coincide with any of the known gases in the stratospheres of Jupiter and Saturn, including C_2H_6. Fourth, a calculation of the band position by S. J. Kim (private communication) shows that the propane band is blended with the R15 line of C_2H_2 on the side of higher frequency as indicated by our data. The identification we propose here is considered tentative because it is based on a single feature, and either the positional accuracy of the available laboratory data is not enough to provide a conclusive identification (± 0.02 cm^{-1} accuracy is required) or the laboratory data was taken at room temperature and the effect of the hot bands complicates the interpretation.

Recently Courtin et al. (1984) have reported the detection of allene (C_3H_4) on Jupiter and Saturn, but none of the prominent allene features matches the emission feature we see as well as that of propane. Indeed, some of the allene features we might expect to see based on the results by Courtin et al. were not observed. These include the $^PP_{10}(11)$ at 738.49 cm^{-1} near the R3 C_2H_2 line at 738.56 cm^{-1}, and the $^PP_9(20)$ and $^PP_9(21)$ lines at 743.71 and 743.07 cm^{-1} near the R5 C_2H_2 line at 743.27 cm^{-1}. The allene line positions are given by Mills, Smith, and Duncan (1965).

III. DISCUSSION

In order to separate the C_2H_2 R7 line emission from the feature with which it is blended, we have calculated the line intensity of the R15 line and adjusted the C_2H_2 stratospheric column density until the calculated and observed intensities matched. Then we calculated the expected R7 line emission, and subtracted it from the observed line flux to obtain the line flux of the blended feature. These results are summarized in Table I.

The radiative transfer program employed to model the lines is similar to that used by Tokunaga et al. (1976). The pressure-temperature profiles for Jupiter and Saturn were taken from Lindal et al. (1981) and Orton (1983), and each atmosphere was divided into 29 layers of approximately 25 km each. The calculation started from the temperature minimum and was continued until the 10^{-5} bar level. Maximum contribution to the line intensity occurred between layers 10 to 20 in all cases. The C_2H_2 abundance variation with height was obtained from Strobel (1974, 1978). Line intensities were calculated following Varanasi et al. (1983), and the Voigt profile was used throughout. To ensure accurate results, the frequency step size was 2×10^{-4} cm^{-1} and the calculation extended 600 Doppler widths from line center (0.5 cm^{-1}).

We calculate a mixing ratio f = $[C_2H_2]/[H_2]$ of 3.1×10^{-8} for Jupiter (see Table 1). This is consistent with values of 6×10^{-9} to 5×10^{-8} obtained by Orton and Aumann (1977) and of less than 2.5×10^{-6} by Festou et al. (1981). For Saturn, we find a value of $f = 1.0 \times 10^{-7}$, which compares well with 2.6×10^{-7} (Moos and Clarke, 1979) and 1.2×10^{-7} by W. Maguire (private communication). The uncertainty in the mixing ratio is ±20%, but it could be higher because we cannot exactly specify the true distribution of the C_2H_2 with altitude.

The presence of propane in the atmospheres of Jupiter and Saturn is expected. Irradiation of pure methane gas by ultraviolet light produces propane, second in abundance only to ethane (Chang et al. 1979). The laboratory experiments cannot reproduce Jovian stratospheric conditions so that only the presence of propane could have been predicted, not the relative abundance. The question of how much propane should be present is a difficult one to answer theoretically since the chemical pathways to produce this gas have not been fully investigated.

In summary, we present evidence for the presence of propane in the atmospheres of Jupiter and Saturn, but the identification of this gas, while very plausible, is not positive. When a definitive identification has been established, the abundance of this gas can be estimated based on the estimated flux shown in Table I. Better data of this type on Titan should help to positively identify this gas.

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TABLE I

INTENSITY OF THE BLENDED FEATURE

	Intensity ($Wm^{-2}\ sr^{-1}$)		
Line	Observed[a]	Calculated[b]	Difference
	Jupiter		
R7 + blend	8.53×10^{-5}	5.03×10^{-5}	3.50×10^{-5}
R15	2.36×10^{-5}	2.36×10^{-5}	0
	Saturn		
R7 + blend	4.23×10^{-5}	2.14×10^{-5}	2.09×10^{-5}
R15	1.19×10^{-5}	1.19×10^{-5}	0

[a] The uncertainty in the intensity is ±10%, primarily arising from the uncertainty in the absolute flux calibrations.

[b] The column shows the calculated intensity of the R7 line after the R15 line intensity is matched to the observations. The mixing ratio, $[C_2H_2]/[H_2]$, calculated from the R15 line, is 3.1×10^{-8} and 1.0×10^{-7} for Jupiter and Saturn, respectively.

FIGURE CAPTIONS

Fig. 1. Spectrum of Jupiter at the expected position of the ν_{21} fundamental Q branch of C_3H_8. It is blended with the R7 emission line of C_2H_2 whose position is indicated by an arrow. The positional accuracy of the C_2H_2 line is ± 0.02 cm^{-1}, and the frequency scale is in vacuum cm^{-1}. Note the greater width of this line compared to the R15 line of C_2H_2.

Fig. 2. Spectrum of Saturn at the expected position of the ν_{21} fundamental Q branch of C_3H_8. The caption of Fig. 1 pertains to this figure as well. Note the symmetry of the R15 line of C_2H_2 compared to this line, indicating another emission band which we attribute to C_3H_8.

Fig. 3. Spectrum of the R15 line of C_2H_2 on Jupiter.

Fig. 4. Spectrum of the R15 line of C_2H_2 on Saturn.

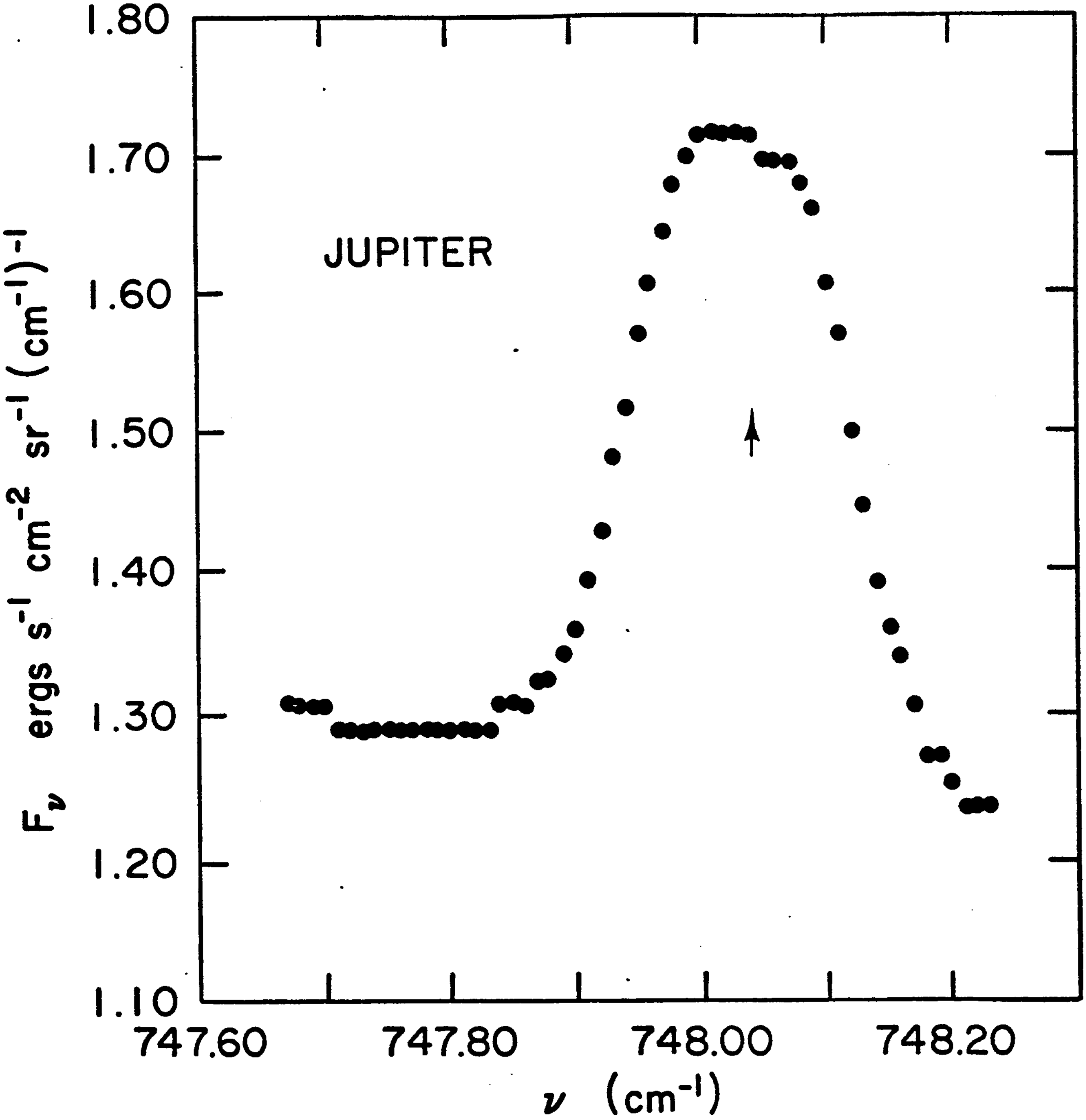
JUPITER
F_ν ergs s^{-1} cm^{-2} sr^{-1} $(cm^{-1})^{-1}$
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
747.60
747.80
748.00
748.20
ν (cm^{-1})

FIGURE 1

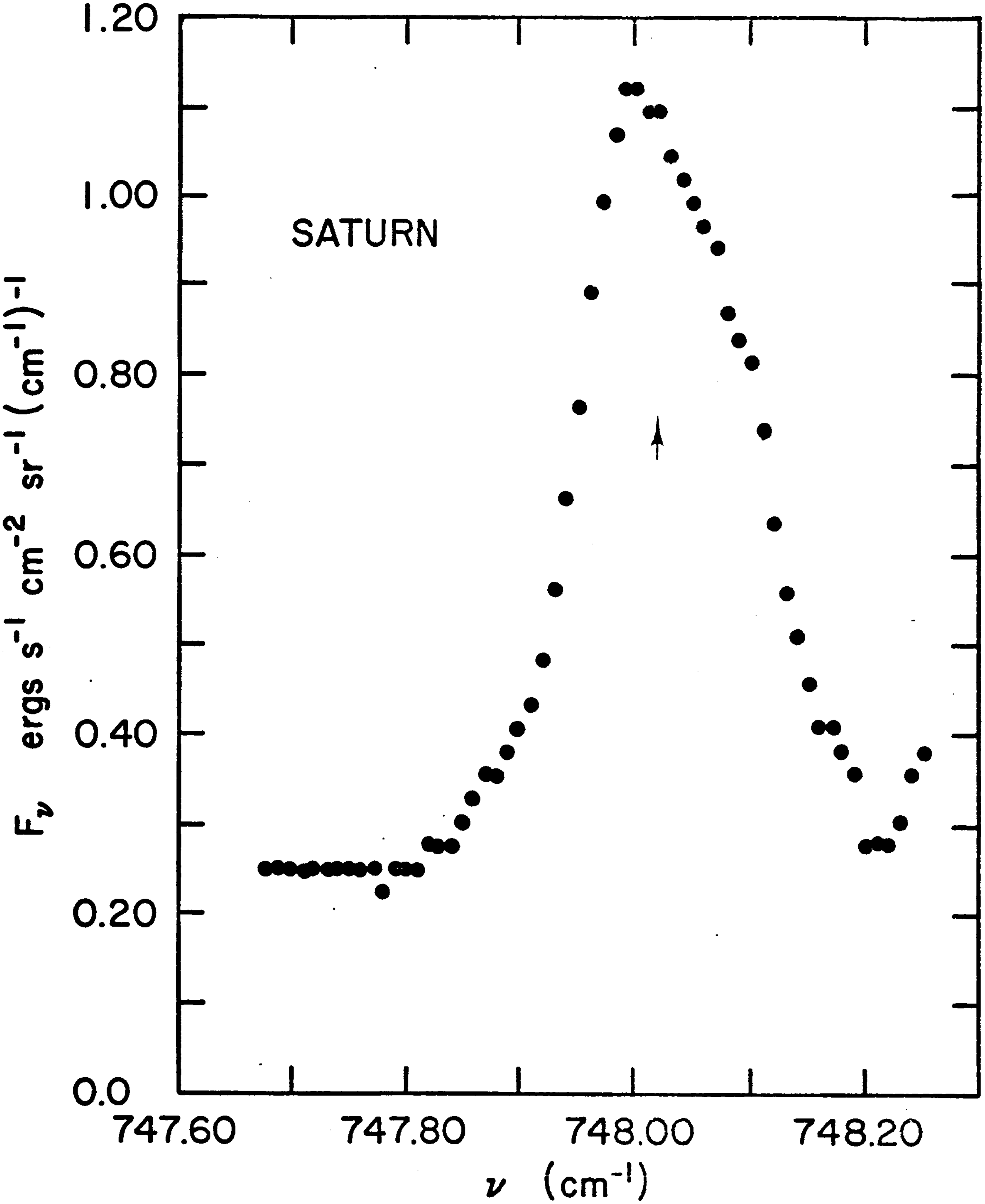
SATURN
F_ν ergs s^{-1} cm^{-2} sr^{-1} $(cm^{-1})^{-1}$
1.20
1.00
0.80
0.60
0.40
0.20
0.0
747.60
747.80
748.00
748.20
ν (cm^{-1})

FIGURE 2

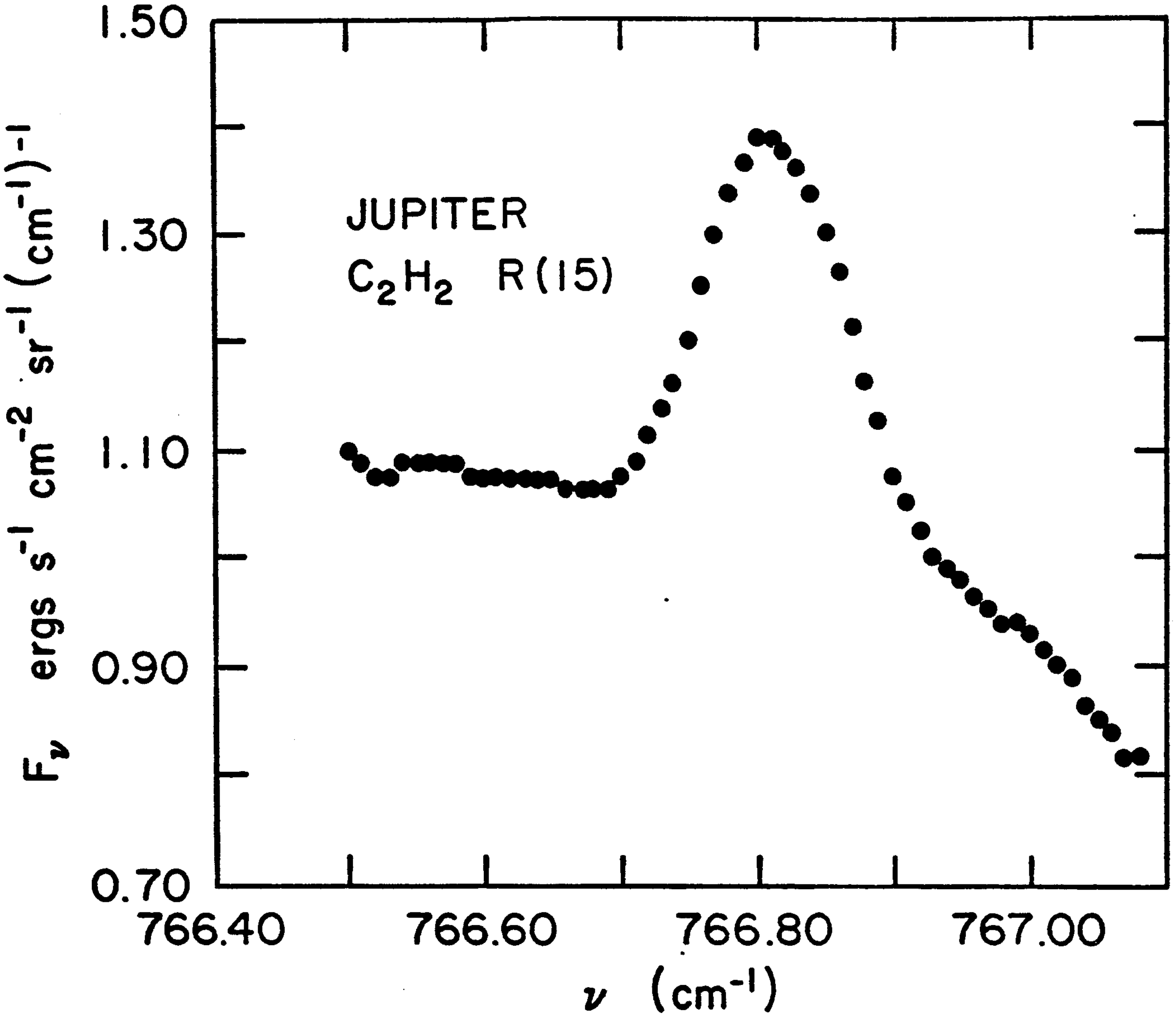
1.50
1.30
1.10
0.90
0.70
766.40
766.60
766.80
767.00
F_ν ergs s^{-1} cm^{-2} sr^{-1} (cm^{-1})$^{-1}$
ν (cm^{-1})
JUPITER
C_2H_2 R(15)

FIGURE 3

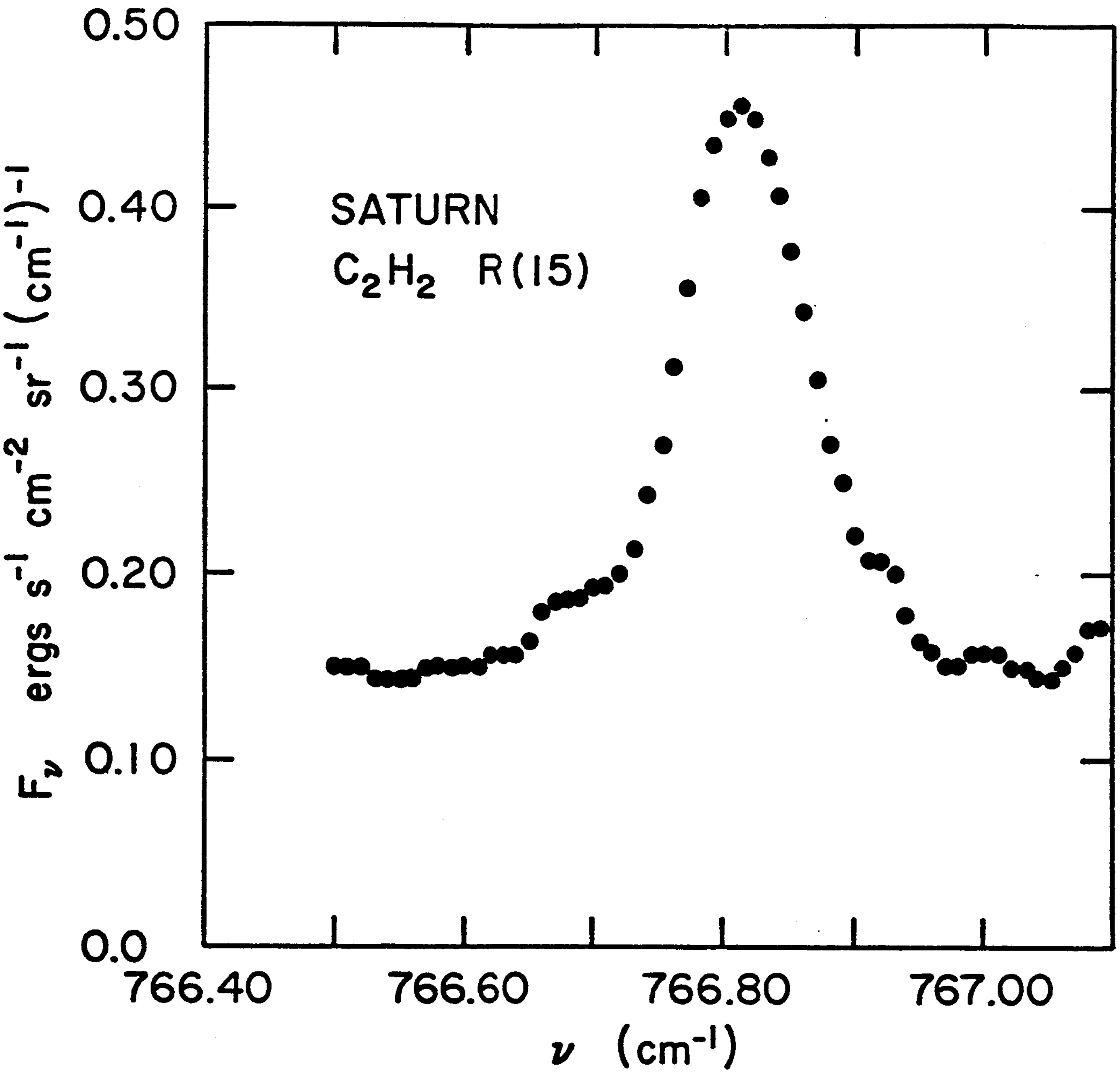
0.50
0.40
0.30
0.20
0.10
0.0
SATURN
C_2H_2 R(15)
F_ν ergs s^{-1} cm^{-2} sr^{-1} $(cm^{-1})^{-1}$
766.40
766.60
766.80
767.00
ν (cm^{-1})

FIGURE 4